

STS-114: Engine Cut-Off Sensors Are a No-Go

Launch Rationale

Review of exhaustive engineering analysis led the Mission Management Team (MMT) to a safety of flight rationale that three of the four sensors reading normal would be acceptable for launch. All hardware related to the failure had been replaced and retested. All orbiter hardware was thoroughly tested and no anomalies were noted. Additionally, the team was confident in their decision because, as former Associate Chief Engineer John Cipolletti points out, “When we were doing this investigation, we actually got the engineer who designed the box out of retirement to come and consult with us and we chatted with him. He was very forthright in saying that when he designed the system he knew if there was a single failure during a launch attempt, you wouldn’t be able to fix it. So he put four [sensors] in so one was a ground throw away and for flight you only needed three [1].” While a total of four sensors protect against a low-level cut-off, only two are required for space shuttle main engine (SSME) shutdown. For a failure of these two sensors to impact flight operations, a hydrogen leak large enough to require a low-level cut-off and a third sensor failure would have to occur [5, p.31]. Engineers also noted that signals from engine cut-off (ECO) sensors 1 and 2 go through different connectors than ECO-3 and ECO-4. While all four sensors go through the same point sensor board (PSB), each sensor has its own independent circuitry inside the box [5, p.32]. Multiple other systems were also in place to protect the SSMEs even if the ECO sensors failed. Through this rationale, the MMT approved a conditional Launch Commit Criteria (LCC) that would permit launch with 3-of-4 functional ECO circuits



Fig. 1. *The flames of Space Shuttle Discovery’s Solid Rocket Boosters are reflected in the water next to Launch Pad 39B as the Shuttle leaps from the pad on the historic Return to Flight mission STS-114 [3].*

given certain conditions [4, p.5]. So as Robert Kichak¹ described it, “With every opinion, point of view, and doubt fully expressed and openly debated” [2], the final decision to launch Shuttle Discovery was approved for July 26, 2005.

Post-Countdown

On July 26, the countdown for STS-114 was flawless and liftoff occurred on time. There were no more issues with ECO sensors throughout the duration of the mission. Both the Discovery vehicle and its crew returned to Earth safely on August 9, 2005 at Edwards Air Force Base, California. It is important to note, however, intermittent anomalies related to the engine cut-off sensors continued to occur after mission STS-114. Multiple initial launch attempts were scrubbed due to failed ECO sensors during pre-launch countdown, including those of missions STS-121 and STS-115 in 2006. Nevertheless, by implementing hardware upgrades, including new wiring, enhancing monitoring capability, and relaxing the LCC requirement, the Shuttle fleet was allowed to continue flying in spite of these unexplained failures [4, p.1]. In fact, the root cause was not determined until STS-122 in December 2007 – more than two years after the ECO sensor anomaly was first investigated.

Several launch attempts in which the anomalies were repeated led to successful detection of the problem area. As Robert Kichak points out, “Ultimately the cause of the problems was conclusively determined to be in the external tank cryogenic feed-through connector. We were finally fortunate enough to have the problem occur and persist with the extra instrumentation in place to determine exactly where it was happening,” [2]. Due to the use of time domain reflectometry (TDR) installed during a December 2007 tanking test, the team was capable of pinpointing an open circuit should it recur. ECO-2 and ECO-3 exhibited erratic behavior during testing while ECO-1 failed wet about 25-30 minutes after sensors were initially wetted. An open circuit was indicated somewhere outside of the PSB according to the ECO voltages. TDR equipment was then plugged into staged break points and the open circuits were isolated to the area of the feed-through connector [4]. Open circuits in the feed-through plate, the part that connects wires from the interior to the exterior of the liquid hydrogen tank, were identified as the culprit causing false readings during launch

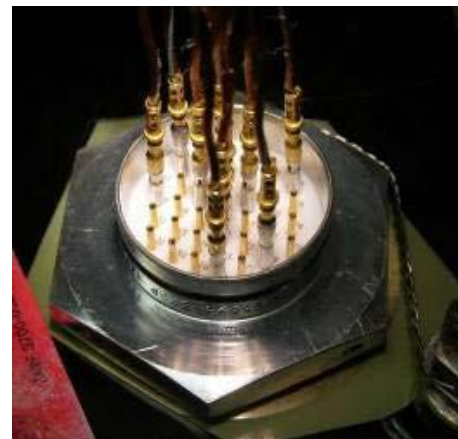


Fig. 2: Soldered pins/sockets [4].

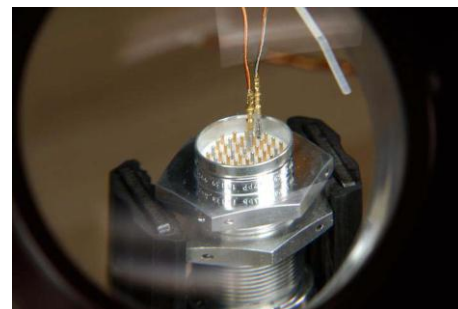


Fig. 3: Modified feed-through connector [6].

¹ Served as the National Engineering and Safety Center (NESC) Discipline Engineer for Avionics; co-author of “STS-114 Engine Cut-off Sensor Anomaly Technical Consultation Report”

attempts and tanking tests. Modifications were made to solder the external harness sockets and the feed-through pins of these connectors together. Once subjected to temperature, pressure, and vibration environments identical to those experienced during a Shuttle launch, the new configuration was verified as adequate and led to successful performance thereafter.

References

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- [4] Martinez, Hugo E. and Ken Welzyn. "Lessons Learned from the Space Shuttle Engine Cutoff System (ECO) Anomalies." Paper presented at the 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, San Diego, CA, July 31-Aug. 3, 2011.
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